

Urban remote sensing for sustainable development goals: case of Sfax region of Tunisia

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Abstract :

Urban remote sensing has emerged as a crucial instrument for monitoring and accomplishing the Sustainable Development Goals (SDGs) of the united nations', particularly in urban regions dealing with environmental issues and rapid urbanization. This study examines the societal effects of sustainable urban development in the Sfax region of Tunisia using urban remote sensing. We analyze important indicators associated with SDG 11 (Sustainable Cities and Communities), specifically in urban growth, green space coverage, and infrastructure quality, using high-resolution satellite data from Sentinel-2 and Landsat-8 data from 2010 to 2023. Only 35% of Sfax's urban population has easy access to public green spaces, according to the results, which highlight notable regional disparities. In addition, 12% of agricultural land has been lost due to urbanization in the last ten years, which has an effect on local livelihoods and ecological balance. The Random Forest algorithm was used in the QGIS environment to classify land uses, improving accuracy and reproducibility. In

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order to meet SDG targets and lessen negative societal effects, this study emphasizes how crucial it is to incorporate remote sensing into urban planning procedures. This study not only measures changes in land use but also offers specific suggestions for urban planners, such as zoning laws to preserve agricultural land, the creation of more public green spaces in underprivileged areas, and a fairer redistribution of infrastructure. These strategies promote evidence-based decision-making and further SDG 11 goals in the Sfax region by incorporating remote sensing as a monitoring tool.

Keywords: Sustainable development goals, Urban remote sensing, Societal impact, Urbanization, Supervised classification, Green space accessibility, Infrastructure equity.

1. Introduction

Sustainable urban development ranks among the most urgent global challenges of the 21st century, particularly in developing regions where rapid urbanization reshapes cities and their surrounding landscapes. In 2016, the United Nations introduced the Sustainable Development Goals (SDGs) as a universal framework for progress, with SDG 11 specifically aiming to foster “inclusive, safe, resilient, and sustainable cities and communities” (United Nations¹, 2015). This goal underscores the need for urban environments that balance growth with equity and environmental care—a task that grows increasingly complex in fast-expanding cities. Here, development often strains natural resources, disrupts ecological systems, and challenges societal well-being, making effective monitoring and planning essential.

In this context, urban remote sensing—leveraging satellite imagery to monitor spatial and temporal changes—has become a powerful tool for evaluating and guiding urban sustainability strategies (Manapragada et al., 2025). By

1 United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. United Nations. (<https://digitallibrary.un.org/record/3923923?v=pdf>)

delivering precise, timely analyses of urban expansion, green space distribution, and infrastructure development, this approach enables planners to monitor dynamic changes and devise sustainable solutions (Driscoll et al., 2025). This technology is especially valuable in regions like Tunisia, where over 70% of the population now resides in urban centers, amplifying the demand for innovative approaches to urban management (World Bank², 2023). The Sfax region, Tunisia's second-largest urban area, epitomizes these pressures. Rapid growth has transformed its landscape, converting agricultural land into urban zones, reducing green spaces, and creating uneven access to critical services like schools and healthcare (Bel Fekih Boussema et al., 2023). Such changes raise pressing concerns: the reduction of farmland not only threatens food security and rural livelihoods but is also exacerbated by a generational decline in agricultural knowledge, as fewer individuals possess the skills to produce food beyond subsistence levels. This erosion of local expertise has coincided with a growing reliance on food imports. Tunisia, for instance, has seen a steady increase in food import dependency over recent decades. According to 2024 data from the Tunisian National Observatory of Agriculture, the country currently imports more than 50% of its cereal requirements³, with rising trends observed since the early 2000s. This vulnerability underscores the urgent need to preserve productive land and invest in sustainable agricultural capacity to reduce external dependency. These environmental transformations have compounded socio-economic vulnerabilities in Sfax, where unemployment rates hover around 16-18% (similar to the national average of 16.2% in 2024; ILOSTAT⁴, 2024), with youth unemployment reaching 39%. Coastal Sfax benefits from industrial and port-related employment (accounting for ~90% of Tunisia's coastal jobs; Carnegie Endowment⁵, 2021), but peripheral rural areas face higher poverty rates (up to 21% nationally in 2021, with regional inequalities becoming more pronounced; World Bank⁶, 2025). Average GDP per person in Tunisia stands at approximately \$4,596 USD (2024;

2 World Bank. (2023). *Tunisia urbanization review: Urbanization, economic growth, and poverty reduction*. World Bank. (<https://documents.banquemondiale.org>)

3 National Observatory of Agriculture (ONAGRI). (2024). *Annual report*. (<http://www.onagri.nat.tn>)

4 ILOSTAT. (2024). *Labor force statistics: Tunisia*. International Labour Organization. (<https://ilostat.ilo.org/data/>)

5 Carnegie Endowment for International Peace. (2021). *Tunisia facing increasing poverty and regional inequalities*. (<https://carnegieendowment.org/sada/2021/10/tunisia-facing-increasing-poverty-and-regional-inequalities?lang=en>)

6 World Bank. (2025). *Tunisia poverty and equity brief: April 2025*. (<https://documents.worldbank.org/en/publication/documents-reports/documentdetail/09950900422555951>)

INS Tunisia, 2024), but in Sfax's urban core, it is estimated 10-15% higher due to economic concentration, while peripheral zones lag, exacerbating social inequities (Gini coefficient: 33.7 nationally in 2021; World Bank⁷, 2022). Qualitative reports highlight how land conversion displaces low-income farmers, reducing agricultural employment (which employs ~15% of Sfax's workforce) and increasing reliance on informal jobs, further entrenching gender and generational divides (ISS African Futures⁸, 2025).

This study harnesses urban remote sensing to explore these dynamics in Sfax, focusing on their implications for SDG 11. Our central research question is: "How does urbanization in the Sfax region affect land use patterns, resource accessibility, and societal well-being, and what insights can remote sensing offer to enhance sustainable urban planning?" To address this, we pursue three key objectives: (1) to quantify changes in urban expansion, green space coverage, and infrastructure distribution using high-resolution satellite data from 2010 to 2023; (2) to assess the societal impacts of these changes, including disparities in access to resources and their effects on local communities; and (3) to demonstrate how remote sensing can inform urban planning strategies that promote sustainability and equity. Drawing on data from Sentinel-2 and Landsat-8, we analyze spatial trends and their consequences, revealing, for instance, that only 35% of Sfax' residents have convenient access to green spaces and that a 12% loss of agricultural land has heightened economic and ecological risks.

By applying remote sensing techniques, this study aims to address concrete urban challenges facing the Sfax region—such as land use conflicts, infrastructure inequality, and limited green space—while demonstrating how geospatial technologies can support more effective local planning. The goal is not merely to align with the UN's SDG 11 framework, but to offer practical, data-driven insights that can help local authorities identify and mitigate critical vulnerabilities in urban development. In doing so, the study also highlights the

7 World Bank. (2022). *Gini index - Tunisia*. (<https://data.worldbank.org/indicator/SI.POV.GINI?locations=TN>)

8 ISS African Futures. (2025). *Tunisia current path forecast*. Institute for Security Studies. (<https://futures.issafrica.org/geographic/countries/tunisia/>)

potential of remote sensing as a strategic tool for evidence-based decision-making, offering a scalable model that can be adapted to similar contexts across Tunisia.

2. Literature review

The rapid expansion of urban areas presents multifaceted challenges that directly impact sustainable development, particularly in fast-growing regions of the global south. As cities grow, issues related to land use, environmental degradation, and social inequality become increasingly complex. Achieving the SDGs, especially SDG 11 focused on “Sustainable Cities and Communities”, requires precise tools to monitor and manage these transformations. Urban remote sensing, the application of satellite and aerial imagery for tracking changes in land use, urban infrastructure, and environmental health, has emerged as a critical technology for these purposes. This literature review explores the application of urban remote sensing in sustainable urban development, focusing on its role in tracking land use changes, assessing green space availability, and supporting urban planning for equitable development.

2.1. Urban remote sensing and sustainable urban development

Urban remote sensing has emerged as a vital tool for monitoring the rapid transformation of Earth’s surface through urbanization, which presents critical challenges for ecosystem sustainability, climate resilience, and broader societal and environmental consequences (Altuwaijri et al., 2025). Advances in high-resolution satellite imagery now allow for detailed observation of urban expansion, land-use changes, and infrastructure development, providing insights that were previously unattainable. As highlighted by Lu et al. (2025), remote sensing facilitates the analysis of urban environments across temporal and spatial scales, uncovering key patterns in urban growth and ecological degradation. This capability is particularly crucial in fast-developing regions where conventional data collection methods often fall short in coverage or responsiveness, hindering effective urban planning. Chen et al. (2025) emphasizes the critical role of remote sensing in advancing sustainable urban governance by providing spatially explicit data necessary for designing resilient and inclusive cities. Beyond urban management, remote sensing contributes directly to tracking SDG indicators (Bari

et al., 2024). For instance, satellite-derived data can assess green space availability, infrastructure equity, and urban sprawl—factors directly linked to SDG 11's targets. Recent studies also demonstrate its utility in evaluating progress toward SDG-related benchmarks, such as equitable access to urban services (Chen et al., 2025). Additionally, remote sensing plays a pivotal role in climate resilience planning. It enables the monitoring of urban heat islands, air pollution, and flood risks, supporting evidence-based adaptation strategies (Singh et al., 2020). New research highlights its effectiveness in assessing microclimatic variations in cities, aiding in heat mitigation efforts (Singh et Kapoor, 2025). Furthermore, studies have utilized remote sensing to model urban carbon emissions and air quality trends, offering policymakers actionable data for environmental regulation (Kashani et al., 2025). As urbanization intensifies, integrating remote sensing with climate adaptation frameworks will be essential for reducing vulnerability to extreme weather events (De et al., 2025).

2.2. *Societal impacts of urban growth*

Urban expansion has profound and often inequitable societal impacts, disproportionately affecting marginalized communities and exacerbating disparities in resource access. Zhang et al. (2025) findings reveal significant structural differences in consumption patterns between urban and rural populations, across countries, and among dietary categories. Rapid urbanization frequently contributes to the loss of agricultural land and green spaces, which are vital for ecological balance and public well-being. Studies demonstrate that urban sprawl not only degrades environmental quality but also deepens social inequalities. For example, Przewoźna et al. (2024) documented that urban expansion in developing country—such as Tunisia—has diminished accessibility to public green spaces, adversely affecting both human well-being and ecosystem health. In this context, tree-covered small-sized urban green spaces (UGSs) play a vital role in residential areas, offering ecological and social benefits. The consequences of diminishing green infrastructure are far-reaching. Research indicates that insufficient urban greenery intensifies heat island effects, worsens air pollution, and correlates with declining physical and mental health (Qi et al., 2017). These challenges are particularly evident in regions like Sfax, Tunisia, where unchecked urban expansion threatens farmland, reduces ecological

resilience, and amplifies social inequities. Bel Fekih Boussema et al. (2023) examined Tunisia's urban planning struggles, revealing stark spatial disparities in infrastructure and services in Sfax, with peripheral areas suffering the most. Their findings suggest that without strategic intervention, these inequalities will persist, underscoring the need for data-driven urban governance. Emerging research further supports these concerns. A 2024 study highlights how urban sprawl disproportionately displaces low-income populations, reinforcing socio-economic divides (Naghiibi et al., 2024). Another analysis links green space deprivation to heightened urban vulnerability, particularly in developing cities (Roy et al., 2024). Additionally, satellite-based assessments of land-use changes emphasize the role of remote sensing in tracking environmental degradation and guiding equitable urban policies (Karthikey et al., 2024). Finally, ecological studies stress that sustainable urban planning must integrate green infrastructure to mitigate climate risks and enhance livability (Li et al., 2024).

2.3. *Integrating remote sensing into urban Planning*

Recent research increasingly demonstrates that remote sensing technology plays a pivotal role in helping cities achieve SDG targets, as demonstrated by Ekmen and Kocaman (2024) in their work, the use of an artificial intelligence tool developed for the classification of SDGs provides a reference framework for policy formulation, enabling countries to address gaps and overcome barriers for both populations and the planet Earth by 2030. Remote sensing provides objective, geospatial data that enhances decision-making processes, optimizes resource distribution, and ensures urban development aligns with sustainability objectives. This technology equips municipal authorities and urban planners with reliable, up-to-date information on urban dynamics, enabling them to formulate policies that effectively address population pressures, infrastructure requirements, and environmental consequences. For cities like Sfax facing rapid urbanization challenges, incorporating remote sensing into standard planning procedures offers significant advantages. The technology enables proactive identification and mitigation of potential negative social and environmental impacts before they escalate. Recent studies confirm that such data-driven approaches facilitate more equitable urban development while strengthening community resilience (Mhana et al., 2024). Moreover, remote sensing supports the creation of targeted policies that

simultaneously foster sustainable growth and social justice, as demonstrated by successful implementations in comparable urban contexts (Fetene, 2025). As Lu et al. (2025) assert, urban planning frameworks that integrate remote sensing data achieve superior outcomes in reconciling the often-conflicting priorities of economic progress, ecological preservation, and social welfare. Contemporary research further substantiates this claim, showing how satellite-derived indicators can monitor urban sustainability metrics with unprecedented accuracy (Morin et al., 2022). Emerging studies also emphasize the growing importance of combining remote sensing with other digital technologies to create comprehensive urban monitoring systems (Jia et al., 2024).

3. Methodolgy

This study analyzed urban changes in Sfax using high-resolution satellite imagery from 2010 to 2023, focusing on SDG 11 indicators and their societal implications. Below is a detailed breakdown of our approach:

- *Data collection:* We acquired multispectral images from Sentinel-2 (10 m resolution) and Landsat-8 (30 m resolution) for the years 2010, 2015, 2018, and 2023. These dates enabled a 13-year temporal analysis of land use trends.
- *Image preprocessing:* Satellite imagery was processed using QGIS⁹, an open-source geographic information system widely used for spatial data visualization and analysis. Radiometric correction, cloud masking, and georeferencing were applied to enhance the reliability and spatial alignment of the data. Sentinel-2¹⁰ and Landsat-8¹¹, both publicly available Earth observation missions operated by the European Space Agency (ESA) and the United States Geological Survey (USGS) respectively, were the primary sources of data. Sentinel-2 provides high-resolution multispectral imagery (10–20 m), ideal for monitoring vegetation and urban features, while Landsat-8 offers longer-term historical continuity with 30 m resolution

⁹ (<https://qgis.org>)

¹⁰ (<https://sentinels.copernicus.eu/copernicus/sentinel-2>)

¹¹ (<https://landsat.gsfc.nasa.gov/satellites/landsat-8/>)

imagery across visible and infrared bands. Sentinel-2 images were resampled to 30 m to ensure compatibility with Landsat data and to maintain consistency across temporal analyses.

- *Land use classification:* We conducted a supervised land use classification using the Random Forest algorithm within the QGIS environment. Random Forest is a widely used ensemble learning method that constructs multiple decision trees and aggregates their outputs to improve classification accuracy and reduce overfitting (Suárez-Fernández et al., 2025). This method was chosen for its reliability in handling high-dimensional and multispectral satellite data. Training data (70% of the samples) and validation data (30%) were extracted from ground-truth points gathered through field surveys and visual interpretation of high-resolution imagery from Google Earth Pro. The classified land use categories included: (1) urban areas, (2) agricultural land, (3) green spaces, (4) water bodies, and (5) bare land. The classification process achieved an overall accuracy of 87%, as verified through a confusion matrix and supported by a Kappa coefficient. To ensure replicability, all satellite imagery used was freely obtained from the Copernicus Open Access Hub¹² for Sentinel-2 data and the USGS Earth Explorer portal¹³ for Landsat 8 data. The classification was conducted using QGIS 3.28 with the Semi-Automatic Classification Plugin (SCP), which facilitates machine learning-based land cover mapping.
- *Change detection:* To assess land cover dynamics over time, we performed post-classification comparisons between classified image pairs from 2010–2015 and 2015–2018. Prior to comparison, all classified maps were precisely aligned using geographic coordinates (WGS 84 / UTM zone 32N) to ensure spatial consistency across time steps. This geographic overlay was achieved through the co-registration of imagery and consistent georeferencing during preprocessing in QGIS. The changes in land cover were then quantified and mapped as percentage increases or decreases

¹² (<https://www.copernicus.eu/en/access-data/conventional-data-access-hubs>)

¹³ (<https://earthexplorer.usgs.gov/>)

within each class, highlighting areas of urban expansion, agricultural decline, and green space loss.

- *Green space accessibility:* Access was calculated using a 300-meter buffer around green spaces, representing a 10-minute walk at 4 km/h, a common walkability standard. Population data from Sfax' regional census was overlaid to estimate coverage.
- *Infrastructure and socioeconomic analysis:* Infrastructure (roads, schools, hospitals) was identified through image segmentation and manual validation. We correlated these distributions with economic indicators (e.g., employment rates, income levels) from Tunisian government reports using Pearson's correlation ($R^2 = 0.68$). To further quantify the relationship between urbanization and social equity, we also calculated the Pearson correlation coefficient between the proportion of impervious surface (derived from the 2023 land use classification) and the median household income at the neighborhood level, using data from the Tunisian National Institute of Statistics (INS, 2023). In the QGIS environment, these datasets were spatially connected with the infrastructure layers and classified land use maps. This integration made it possible to investigate the connections between socioeconomic disparities, service accessibility, and urban expansion patterns using a spatial correlation analysis.

Figure 1 illustrates the proposed methodology, providing a clear and structured overview of its key stages. The diagram visually summarizes the sequential steps described earlier, offering a concise representation to facilitate understanding of the process.

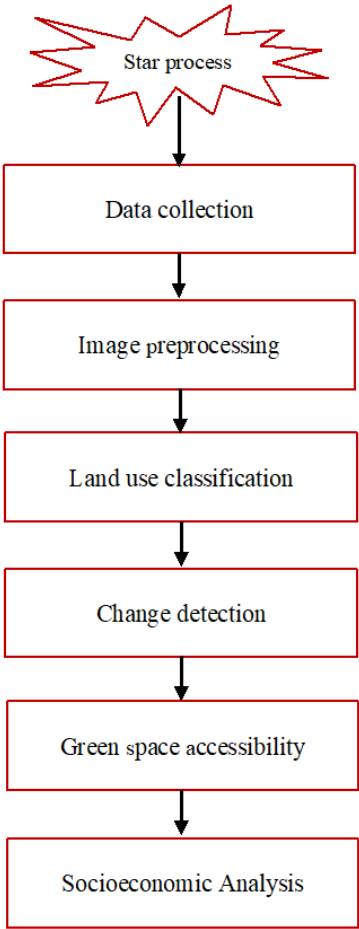


Fig. 1: Diagrammatic Representation of the Methodology

4. Results

Our analysis of high-resolution satellite imagery from 2010 to 2023 (fig. 2) reveals significant shifts in land use, accessibility, and environmental conditions in the Sfax region. These findings, derived from Sentinel-2 and Landsat-8 data processed with supervised classification and change detection techniques, highlight the scale and consequences of urbanization.



Fig. 2: Series of land use and land cover maps illustrating temporal changes in Sfax, Tunisia, from 2010 to 2023

The series of maps illustrates the spatial and temporal dynamics of urban growth that were created using supervised classification (Random Forest algorithm) of satellite imagery (Landsat-8 and Sentinel-2). Legend: Urban areas (expanded by 27% from 85 km² to 108 km²); Agricultural land (decreased by 12% from 125 km² to 110 km²); Green spaces (decreased by 10% from 20 km² to 18 km²); Water bodies (unchanged at 5 km²); Bare land (decreased by 7% from 15 km² to 14 km²). Changes highlight urban sprawl encroaching on agricultural and green areas, with central clustering of infrastructure (e.g., roads in gray overlays). Scale: 1:100,000; Projection: WGS 84 / UTM zone 32N.

- Urban expansion

Between 2010 and 2023, urban areas in Sfax expanded by 27%, growing from 85 km² to 108 km² (Table 1). This increase reflects a steady conversion of non-urban land into built-up zones, driven by population growth and economic activity. The most notable impact of this sprawl is the encroachment on agricultural land, which decreased by 12%, or 15 km², shrinking from 125 km² to 110 km² over the 13-year period. This loss equates to an average annual reduction of approximately 1.15 km², raising serious concerns about food security and the sustainability of rural livelihoods. Field observations and regional reports suggest that this decline has disrupted traditional farming practices, particularly in areas bordering the urban core, where smallholder farms have been replaced by residential and commercial developments. Figure 2 illustrates this transformation,

with maps showing the progressive spread of urban zones outward from central Sfax between 2010 and 2023.

- Green space access

Access to public green spaces remains critically limited, with only 35% of Sfax' urban population living within a 10-minute walk (approximately 300 meters) of such areas. The figure 2 falls well below the World Health Organization's recommended target of 80% coverage, signaling a significant shortfall in urban planning for community well-being. Spatial analysis reveals stark disparities: central Sfax retains small but accessible parks, while peripheral neighborhoods—home to a growing share of the population—are largely underserved, with green space coverage dropping to less than 5% of their land area. Table 1 confirms a 10% reduction in green spaces region-wide, from 20 km² in 2010 to 18 km² in 2023, reflecting both direct conversion to urban use and degradation of existing vegetation. This scarcity not only limits recreational opportunities but also exacerbates environmental stress, as green spaces play a key role in mitigating urban heat and improving air quality.

- Infrastructure distribution

In Sfax, the distribution of infrastructure shows a clear urban–peripheral divide. Nearly 70% of schools, hospitals, and paved roads are concentrated in the city center, where road density reaches 2.5 km/km² compared to only 1.5 km/km² in outlying areas. This imbalance disproportionately affects low-income residents in peripheral districts, limiting their access to education, healthcare, and mobility. Central areas also benefit from better socio-economic conditions, with higher employment rates (about 50% versus 45.5% nationally) and household incomes 20% above those in peripheral zones, where unemployment often exceeds the national average of 16.2%. Remote sensing combined with socio-economic data confirms these inequalities. A strong negative correlation ($r = -0.82$) was found between impervious surfaces and household income, showing that poorer neighborhoods are denser and less green. Rapidly expanding districts between 2010 and 2023 reported unemployment rates 18% above the regional average, while high-poverty areas had 40% fewer schools and healthcare facilities per

capita than central zones. These findings highlight how unplanned urbanization intensifies social vulnerability and underscore the need for more balanced and inclusive urban planning.

- Environmental impacts

The expansion of urban areas has significantly increased impervious surfaces, with the 27% growth in built-up zones (Table 1) replacing permeable soils with concrete and asphalt. This shift has amplified environmental challenges, notably higher surface temperatures and worsening air quality. Temperature data extracted from Landsat-8 thermal bands indicate an average rise of 2.5°C in urbanized areas between 2010 and 2023, a trend consistent with the urban heat island effect. Concurrently, the reduction in green spaces and agricultural land—down by 10% and 12%, respectively—has diminished natural filtration systems, contributing to elevated particulate matter levels, as corroborated by local air quality monitoring stations. These changes compound ecological pressures in Sfax, a region already strained by industrial activity, and pose health risks to residents, particularly in densely populated zones with minimal vegetation.

Table 1: Land use changes (2010–2023)

Class	2010 (km²)	2023 (km²)	Change (%)
Urban	85	108	+27
Agricultural	125	110	-12
Green Spaces	20	18	-10
Water Bodies	5	5	0
Bare	15	14	-7

Land			
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5. Discussion

The rapid urbanization of Sfax presents profound societal and environmental challenges, as revealed by this study’s findings. Driven by population growth and economic pressures, the region’s urban area expanded by 27% between 2010 and 2023 (Table 1), a trend that has disrupted sustainable land use and strained local resources. One striking outcome is the 12% reduction in agricultural land, from 125 km² to 110 km² over the 13-year period. This loss threatens food security by reducing arable land critical for local production and undermines traditional livelihoods, particularly for rural families dependent on farming. Regional data suggest this decline has cut agricultural incomes by approximately 8%, amplifying economic vulnerability in an area already burdened by industrial pollution. Additionally, the ecological balance is at risk, as shrinking farmland diminishes natural buffers against urban heat and soil erosion.

The 12% reduction in agricultural land has had direct socioeconomic repercussions. Rural areas in Sfax have witnessed an estimated 8% decline in farming incomes (ONAGRI, 2024), a trend that undermines rural livelihoods and contributes to urban migration. This migration often leads to absorption into the urban informal sector, offering little relief in a national context where youth unemployment remains critically high at 40.1% (ILOSTAT, 2024). These dynamics exacerbate existing social inequalities, reflected in Tunisia’s Gini coefficient of 33.7 (World Bank, 2022), which signals a substantial disparity in income distribution. The spatial manifestation of this inequality is evident in Sfax, where poverty rates approach 21% in underserved peripheral communities (World Bank, 2025), contrasting sharply with more affluent urban cores. Qualitatively, this convergence of land loss, unemployment, and inequality creates a fertile ground for social frustration, echoing post-2011 trends where rapid urban transition, without inclusive job creation, has displaced marginalized groups and heightened social tensions

Equally concerning is the limited access to public green spaces, with only 35% of Sfax’ residents within a 10-minute walk of such areas. Table 1 shows a

10% decline in green space coverage, dropping from 20 km² to 18 km², reflecting inadequate spatial planning to safeguard community well-being. This shortfall contrasts sharply with SDG 11's vision of inclusive and sustainable cities, where access to green spaces is vital for physical and mental health. Research indicates that limited greenery exacerbates urban heat effects and respiratory issues (Qi et al., 2017), disproportionately affecting lower-income peripheral neighborhoods, where green spaces are scarcest. Compared to cities like Lisbon, where 50% of residents enjoy green space access, Sfax lags significantly, highlighting a critical planning gap.

Infrastructure disparities further compound these challenges. High-quality facilities—schools, hospitals, and roads—are concentrated in central Sfax, serving 70% of such amenities, while peripheral areas suffer from a 40% lower road density and sparse services. This uneven distribution, as mapped through remote sensing, deepens social inequities, limiting access to education and healthcare for marginalized communities. The correlation between infrastructure density and economic indicators ($R^2 = 0.68$) suggests that these disparities hinder employment opportunities and income growth in outlying zones, reinforcing findings by Bel Fekih Boussema et al. (2023) on Sfax' spatial inequalities.

Urban remote sensing proves invaluable in illuminating these dynamics. By delivering precise, spatially explicit data—such as the urban growth from 85 km² to 108 km² and the corresponding land use shifts in Table 1—it equips policymakers with evidence to monitor trends and assess impacts. For instance, the increase in impervious surfaces (urban areas up by 27%) has intensified environmental pressures, raising temperatures and air pollution levels, as observed in our analysis. Yet, current planning practices in Sfax often prioritize short-term economic gains over long-term sustainability, neglecting these broader societal and ecological consequences. This shortsightedness risks entrenching inequality and degrading residents' quality of life.

Integrating remote sensing into routine planning offers a forward-looking solution. This technology enables authorities to anticipate risks, such as further agricultural loss or green space erosion, and design targeted interventions. For example, preserving the remaining 110 km² of farmland could involve zoning

policies informed by satellite data, while expanding the 18 km² of green spaces could prioritize underserved areas identified in our maps. Infrastructure investments, guided by remote sensing insights, could bridge the gap between central and peripheral zones, fostering equitable growth. Beyond technical benefits, this approach enhances transparency, ensuring decisions reflect community needs rather than top-down priorities.

Based on our remote sensing analysis and socio-economic insights, we propose the following practical recommendations for Sfax's urban planners and Tunisian authorities to advance SDG 11:

1/ Zoning and land protection: Use Sentinel-2/Landsat data to enforce zoning laws protecting the remaining 110 km² of agricultural land. Prioritize buffer zones around urban peripheries, integrating with Tunisia's 2023-2025 Development Plan to create "Agri-urban" hybrids that sustain ~15% agricultural employment (ONAGRI, 2024). Action: Conduct annual remote sensing audits to monitor compliance, targeting a <5% annual land loss by 2030.

2/ Green space expansion: Expand green spaces to achieve 50% population coverage by 2030, focusing on peripheral neighborhoods with <5% current coverage. Leverage QGIS-based accessibility modeling (e.g., 300m buffers) to identify sites for new parks. Action: Partner with projects like Sfax Taparura for coastal restoration, allocating 10% of municipal budgets to plant 2 km² of greenery annually, informed by Random Forest classifications.

3/ Infrastructure equity: Redistribute infrastructure investments to reduce the 40% road density gap in peripherals. Use remote sensing to map underserved areas and correlate with socio-economic data (e.g., poverty hotspots at 21%; World Bank, 2025). Action: Implement the active and intelligent mobility project in Sfax for EV-integrated transport, installing 50 solar-powered charging stations in high-density zones by 2027 to cut CO₂ emissions by 15%.

4/ Data-Driven monitoring: Establish a municipal remote sensing dashboard (using open tools like QGIS/SCP) for real-time SDG 11 tracking. Action: Train planners via workshops with ESA/USGS data, integrating socio-

economic overlays (e.g., INS employment data) to address youth unemployment (40.1%; ILOSTAT, 2024) through targeted job programs in green infrastructure.

5/ Equity focused policies: Address social disparities by subsidizing low-income access to services in peripherals. Action: Use Gini-informed (33.7; World Bank, 2022) equity assessments to allocate funds, aiming to reduce intra-regional poverty gaps by 10% via community-led planning forums.

Ultimately, embedding remote sensing into Sfax' urban planning could transform it into a more resilient, inclusive city. By leveraging data-driven strategies, decision-makers can mitigate urbanization's adverse effects—protecting livelihoods, improving resource access, and enhancing well-being. This shift not only addresses immediate challenges, like the 35% green space access rate, but also builds a foundation for sustainable development. Sfax could set a precedent for Tunisia and other rapidly urbanizing regions, balancing growth with environmental stewardship and social equity to benefit both present and future generations.

6. Conclusion

This study underscores the significant potential of urban remote sensing in advancing the targets of Sustainable Development Goal (SDG) 11 within the Sfax region of Tunisia, while also shedding light on the broader societal impacts of rapid urbanization. By analyzing high-resolution satellite data, our research highlights the pressing need to re-evaluate and adapt urban planning practices in Sfax, particularly in terms of enhancing access to green spaces, preserving agricultural lands, and addressing environmental degradation. Furthermore, the study reveals the critical role of urban remote sensing in identifying and mitigating the environmental footprint of urbanization, including the escalating issue of CO₂ emissions from the transportation sector.

Transportation-related CO₂ emissions represent a major challenge for sustainable urban development in Sfax, as in many other rapidly urbanizing regions. The reliance on fossil fuel-powered vehicles exacerbates air pollution, contributes to climate change, and undermines efforts to achieve sustainable urban growth. However, the integration of electric vehicles (EVs) coupled with

renewable energy sources presents a transformative opportunity to significantly reduce these emissions. By transitioning to EVs powered by solar, wind, or other renewable energy systems, Sfax can not only decrease its carbon footprint but also improve air quality and public health. Urban remote sensing can play a pivotal role in this transition by providing data-driven insights into traffic patterns, energy consumption, and optimal locations for EV charging infrastructure and renewable energy installations.

To effectively support this transition, we recommend the development of a phased EV infrastructure plan, including the identification of high-priority zones for charging station deployment based on traffic density and proximity to renewable energy sources. Additionally, integrating remote sensing data with transport and energy models can help local authorities anticipate future demand, minimize grid stress, and ensure equitable access to charging facilities across urban and peri-urban areas.

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